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Effect of Water Flow Rate, Casting Speed, Alloying Elements and Pull Distance on Tensile Strength, Elongation Percentage and microstructure of Continuous Cast Copper Alloys

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Abstract

Most parameters that control the solidification of castings, and consequently, microstructure and mechanical properties, are: chemical composition, liquid metal treatment, cooling rate and temperature gradient. In this work, characterization of the influence of water flow rate, casting speed, alloying element and pull distance on tensile strength, elongation percentage and microstructure of continuous cast copper alloys has been carried out. A significant difference based on tensile strength, elongation percentage and grain structure has been investigated and it was also found that these parameters could improve the physical and mechanical properties of samples. As a particular example, water flow rate could improve the elongation of samples from 10% to 25%.

1. Introduction

Copper alloys have been used for at least 7,000 years, mostly due to their beneficial characteristics such as excellent electrical and thermal conductivity, high corrosion resistance and easy processing. The major applications of copper alloys are for wires, electronic devices, industrial machinery and pipes for heating systems [1]

Various copper components in the form of rod, tube, strip and sections are produced by the continuous casting process [2]. Continuous casting is a process of melting and continuous solidification and it has been used for more than 100 years to produce components. Now, the continuous casting process produces over 1 MT of copper in the world each year [3, 4]

The continuous casting process is less expensive than thermo-mechanical processes such as extrusion, but the metallurgical and mechanical properties of components produced by continuous casting such as tensile strength or elongation percentage are lower than those produced by thermo-mechanical processes [5, 6]

In the continuous casting process, further downstream processes such as drawing or rolling are commonly used to improve both tensile strength and elongation percentage performance of as-cast rod. However, alloying elements and grain refinement have also been reported as techniques to enhance the mechanical properties of as-cast copper alloys. Grain refinement techniques,

which can refine the matrix, improve the morphology and distribution of the second phase and enhance mechanical properties [7, 8]
The thermal method is a known grain refinement method to produce metals with small grains and better ductility by controlling the cooling rate [9]
The aim of this paper is to investigate the impact of the alloying elements and cooling control on mechanical properties of continuous cast copper and copper alloys.

2. Materials for Research

The material preparation, set-up, casting procedure, casting parameters and tensile test analysis are explained from section 2.1 to 2.4.

2.1 Material Preparation

The copper alloys were produced from dry, clean, bright, flat, un-oxidized copper cathode feedstock, free from electrolyte nodules. The copper cathode feedstocks were melted in a graphite crucible using graphite heating element furnace technology (Rautomead RS continuous casting machine). The chemical composition of the cast alloy was then tested using an AMETEK spectrometer.

2.2 Set-up

All casting trials were carried out on the model RS080 vertically upwards-continuous casting machine at Rautomead's premises in Dundee. Standard Rautomead vertical continuous casting parameters and withdrawal system set-up for 8 - 22 mm rod was utilized, which consisted of pull distance, push distance, pull dwell, acceleration and deceleration, casting speed and water flow rate.

2.3 Casting Procedure (Rautomead RS continuous casting machine)

The Rautomead RS (commercial name) vertical upwards casting machine is designed for the production of 8.0 mm diameter wire rods. This machine may also be designed to produce rod up to 22.0 mm diameter dependant on customer requirements. Rautomead vertical upwards casting machines are designed to be operated for long periods of continuous production of continuous cast copper wire rod, and are configured as integrated melting, holding and casting units, featuring graphite crucibles, protected in an inert gas atmosphere with high intensity graphite resistance heating. The Rautomead vertical upwards casting machines for rod/tube production have the advantages of low energy consumption, low maintenance cost, small capital investment, no scrap rate and no waste pollution in production. This will be explained in more detail below.

2.3.1 Main parts of RS Machines:

The main components of the RS continuous casting machine are as follows:

1) The resistance furnace comprises a furnace body and furnace frame, and is used to melt copper cathode or scrap into liquid and keep the liquid at a constant temperature.

Rautomead furnace technology is unique because graphite is employed for containment (crucible and valve), casting (die and packers) and heating elements (resistance heating).

2) Continuous casting machine which is the main part of the system and consists of a drawing mechanism, called the withdrawal.
3) Cooling system.
4) Electrical control system (control panel).
5) Cathode feed system.
6) Coilers.

Figure 1 shows the schematic of continuous rod casting machine

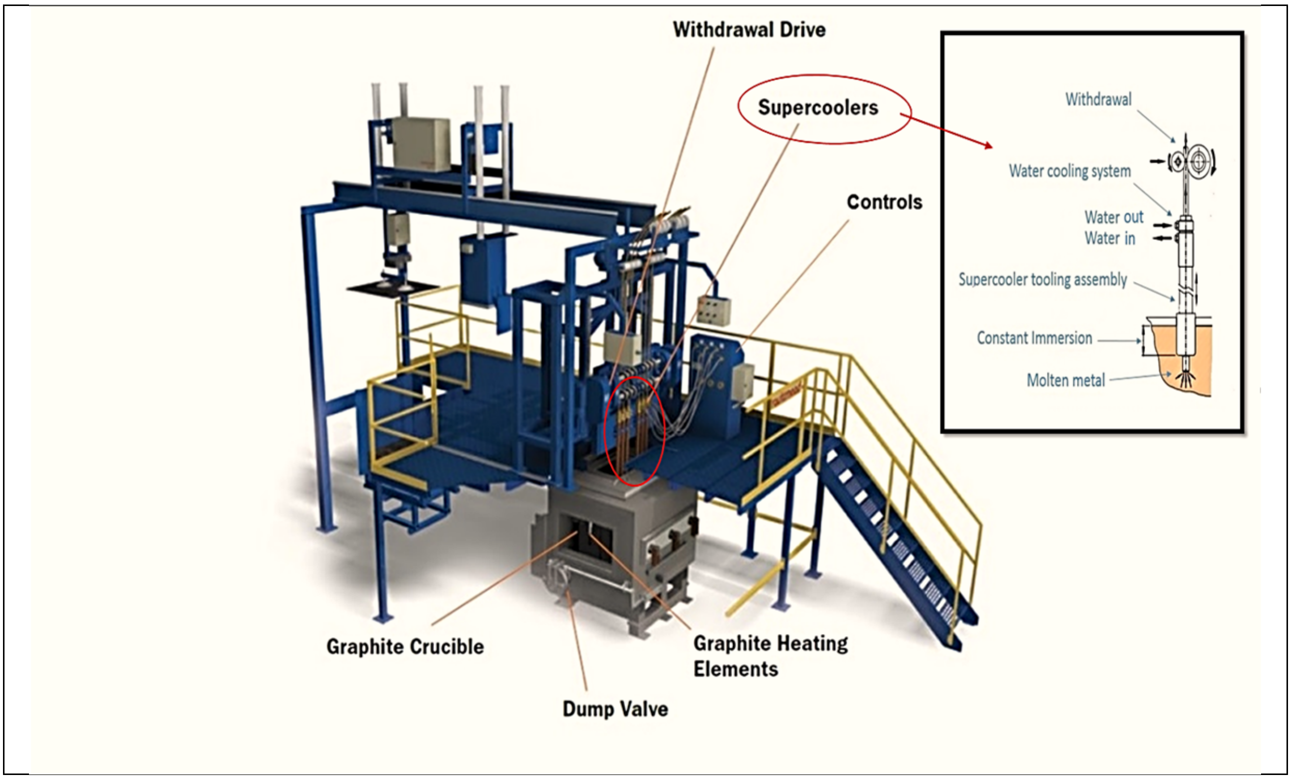


Fig. 1. Schematic of Continuous Rod Casting Machine

2.3.2 Continuous Casting withdrawal System

The withdrawal cycle in continuous casting is introduced by Haissig and Voss-Spilker and Reichelt in 1984 [10,11]

In the continuous casting process, generally four different withdrawal cycles are used including: [12]

1- Non-intermittent extraction which is usually used for casting alloys with low temperature interval of solidification such as pure metals or casting at high cooling rate.
2- Intermittent extraction with a pause, which is used for casting of copper alloys at lower cooling rates.
3- Intermittent extraction with one push-back, which usually used for the kind of alloys

having wide temperature interval of solidification.

4- Intermittent extraction with two push-back which is used for casting alloys containing constituents penetrating into the graphite pores and causing sticking the casting to the graphite surface.

2.3.3 Main casting parameters

The quality of continuous cast copper rod largely depends on microstructure as well as mechanical properties like tensile strength and elongation percentage. The control of the grain structure, which develops during solidification processes, is a key issue for the optimisation of the final mechanical properties. These can be improved by analyzing and optimizing the process parameters during the casting process such as:

- Cooling water flow rate
- Casting speed
- Pull distance
- Melt temperature
- Withdrawal system
- Continuous casting direction
- Super cooler size
- Casting die materials

It is also important to select the right withdrawal cycle. Generally, the continuous casting process is controlled automatically, but the quality and productivity of resulting product is dependent on the casting parameters used during the casting process. Proper withdrawal cycle and casting parameters selection is critical to the ultimate success of the continuous casting process. This paper will discuss the effect of cooling water flow rate, casting speed and pull distance on physical and mechanical properties of continuously cast copper and copper alloys.

2.4 Tensile Testing

A tensile test was performed to investigate the tensile strength (MPa) of the material as well as to find the ductility in terms of elongation percentage of the alloy. The test specimens were prepared according to ASTM standard. The specimens were tested using a computerised universal testing machine (Make: Instron; Model: 4204).

2.5 Metallography

Samples for microstructural observations were cut with a clean sharp hacksaw. Sectioning of the test sample was performed carefully to avoid destroying the structure of the material. After the sample is sectioned to a convenient size, samples were then ground by using coarse abrasive paper (Grade No 60), and subsequently wet & dry fine silicon carbide paper (Grit No 2500) SiC papers, and polished on a cloth with a diamond suspension and lubricating solution. The grinding and polishing were both carried out on a Struers machine. After polishing, the samples were cleaned by acetone in an ultrasonic cleaner and dried with nitrogen gas. In the chemical etching process, nitric acid and distilled water were used.

3. Experiment

3.1 Water Flow Rate

The aim of this section was to understand the efficiency of water flow rate on tensile strength and elongation percentage of continuous cast copper alloy. The trial produced a vertically upward cast 8mm diameter CuSnP sample. The alloy was Sn 0.65% and P 0.03% balance Cu. In this investigation several small batches of samples were cast at different water flow rate conditions. Different water flow rates have been studied in this research and then the elongation percentage of continuous cast rod was measured by universal tensile machine. Three samples were selected, and an average taken. Table 1 provides the results from the copper samples tested in this study.

Table 1. CuSnP samples tested in this research

Sample	Rod dia (mm)	Die	Pull Distance (mm)	Pull Dwell (sec)	Acceleration (sec)	Deceleration (sec)	Casting Speed (mm/min)	Water Flow Rate (ltrs/min)
Cast 1	8	Graphite	10	0	0.02	0.02	3500	15
Cast 2	8	Graphite	10	0	0.02	0.02	3500	20
Cast 3	8	Graphite	10	0	0.02	0.02	3500	30
Cast 4	8	Graphite	10	0	0.02	0.02	3500	40
Cast 5	8	Graphite	10	0	0.02	0.02	3500	45

3.2 Casting Speed

Previous research shows that casting speed is one of the major controlling parameters of the metallurgical quality of the cast product [13]

The aim of this section was also to obtain the relationships between casting speed and mechanical properties of continuous cast copper alloy. Low and high casting speed coils of OFCu continuous cast copper were produced, and the elongation percentage and tensile strength was calculated on all investigated specimens. The representative copper samples analysed in this research are listed in Table 2.

Table 2. OFCu samples tested in this research

Sample	Rod dia (mm)	Die	Pull Distance (mm)	Pull Dwell (sec)	Acceleration (sec)	Deceleration (sec)	Water Flow Rate (ltrs/min)	Casting Speed (mm/min)
Cast 1	8	Graphite	0.5	0.2	0.005	0.005	45	2500
Cast 2	8	Graphite	0.5	0.2	0.005	0.005	45	4500
Cast 3	8	Graphite	0.5	0.2	0.005	0.005	45	6000
Cast 4	8	Graphite	0.5	0.2	0.005	0.005	45	7800

3.3 Alloying Elements

It has been previously reported that the level of alloying element plays a significant role in determining the properties of casting alloys [14]

Although the relationship between the ultimate tensile strength (UTS) and the electrical conductivity (EC) for drawn CuZr binary alloy wires and other conventional copper alloys has been reported, the effect of increasing zirconium content on the mechanical properties of continuous cast copper alloy has not been investigated previously. In this paper the effect of zirconium on the mechanical properties of continuous cast copper alloy is investigated.

Experimental work to produce 15 mm diameter CuZr rod were performed to evaluate the effect of alloying elements on mechanical properties of CuZr alloys. In this study, several small batches of samples were cast using different Zr alloy content. In order to investigate the alloying effect of Zr on the mechanical properties of CuZr alloy, a tensile test at room temperature was carried out according to ASTM standard. Alloy contents are summarised in Table 3. Three samples of each alloy were selected and an average taken and then from the generated data the ultimate tensile strength and percentage elongation of each alloy sample was calculated.

Table 3. CuZr samples tested in this research

Sample	Rod dia (mm)	Die	Pull Distance (mm)	Pull Dwell (sec)	Accele ration (sec)	Deceleration (ec)	Water Flow Rate (ltrs/min)	Casting Speed (mm/min)	Zirconium percentage (%)
Cast 1	12	Graphite	9	0.5	0.2	0.2	45	1400	2.67
Cast 2	12	Graphite	9	0.5	0.2	0.2	45	1400	2.80
Cast 3	12	Graphite	9	0.5	0.2	0.2	45	1400	3.45
Cast 4	12	Graphite	9	0.5	0.2	0.2	45	1400	6.80

3.4 Pull Distance

In the continuous casting process, the distance of one pull in one cycle for withdrawing the cast is called pull distance. One of the purposes of this work was to experimentally investigate the dependency of the pull distance and mechanical properties of continuous cast copper alloys.

The cast trial was attempted using a standard Rautomead upward continuous casting machine setup for 8 mm rod, which consisted of varying pull distance. The alloy was 0.3 % Sn balance Cu. The tensile test of the Cu0.3%Sn cast alloys was conducted at room temperature using a universal tensile testing machine with a gauge length of 100mm and cross-head speed of 10 mm/min. For each test, percent elongation was calculated using Hooke's law. The representative Cu0.3%Sn copper samples analyzed in this work are listed in Table 4.

Table 4. CuSn samples tested in this research

Sample	Rod dia (mm)	Die	Pull Dwell (sec)	Acceleration (sec)	Deceleration (sec)	Water Flow Rate (ltrs/min)	Casting Speed (mm/min)	Pull Distance (mm)
Cast 1	12	Graphite	0.015	0.010	0.010	55	970	3
Cast 2	12	Graphite	0.015	0.010	0.010	55	1700	4
Cast 3	12	Graphite	0.015	0.010	0.010	55	2100	5
Cast 4	12	Graphite	0.015	0.010	0.010	55	2700	6

4. Results and Discussion

4.1 Water Flow Rate

The objective of this study was to find the effect of water flow rate on the mechanical properties of continuous cast copper rod by varying water flow rates. After cooling experiments, the tensile strength has been examined, and it was found that increase in water flow rate affects the tensile strength and elongation percentage. The results of average elongation percentage of copper alloy samples are presented in Figure 2.

Table 5 shows the tensile strength and average elongation percentage of the continuous cast copper rod samples, explained on Table 1. It can be seen that sample 1 has the highest elongation percentage, therefore a conclusion could be that the water flow rate might improve the elongation percentage of samples from 10 % to 25 %. In the continuous casting process, water is used to cool the mould in the initial stages of solidification. So water flow rate in continuous casting plays a key role in transforming heat from the mould and solidifying metal during the continuous casting of copper and copper alloys. It has also been previously reported that water flow rate is one of the main process parameters that can change upon direct chill casting because increasing the water flow in the mould increases the heat- transfer rate, and thereby decreases the mould temperature [15,16].

Water-cooling affects the product quality by (1) controlling the heat removal rate that creates and cools the solid shell and (2) generating thermal stresses and strains inside the solidified metal [17]. When the cooling rate is slow, some of the large clusters of atoms in the liquid develop interfaces and become the nuclei for the solid grains that are to form. During solidification the first nuclei increase in size as more and more atoms transfer from the liquid state to the growing solid. Eventually all the liquid transforms and large grains develop. The grain boundaries represent the meeting points of growth from the various nuclei initially formed. Low cooling rate result in a less homogeneous micro-structure. When the cooling rate is fast, many more clusters develop, and each grows rapidly. As a result more grains form and the grain size in the solid metal is finer [18, 9].

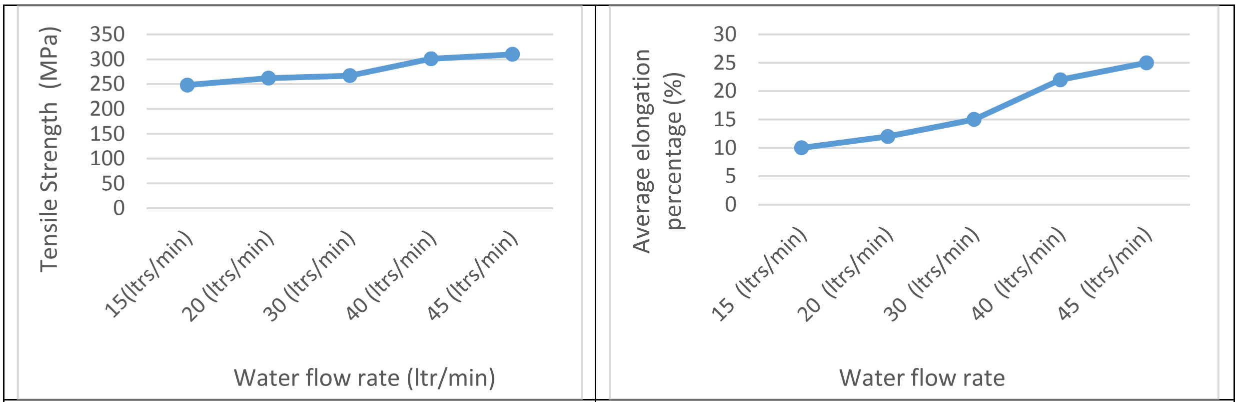
The effect of water flow rate on the structure of the continuous cast copper rod is illustrated in Figure. 3. From these figures, it can be observed that fine grains can be achieved by increasing the water flow rate. Water flow rate is known to affect the structure formation during solidification. This is because of its influence on cooling condition. So, it was observed that the cooling rate has a very significant effect on the grain size of rods. This observation is defined with following phenomena:

1- Faster cooling results in large values of growth velocity, which results in an increase in the number of effective nucleants and a finer grain size.
2- Faster cooling results in increase in the degree of constitutional and amount of undercooling, which results in fine grain structure.

As well as the above phenomena, water-cooling plays a major role in extracting heat from both the casting die and solidifying metal during the continuous casting procedure.
Generally, an increase in strength results in an increase in brittleness, and increase in elongation illustrates an increase in ductility of material. So, if strength increases, elongation is generally decreased, which means that tensile strength and elongation percentage, are generally contradictory to each other. However, homogenizing (and the resultant grain refinement) increases both strength and ductility. This similarly occurs when we increased the water flow rate.
As a summary, all these phenomena confirmed water flow rate has an important impact on the physical and mechanical properties of continuous cast copper alloy [19, 20].

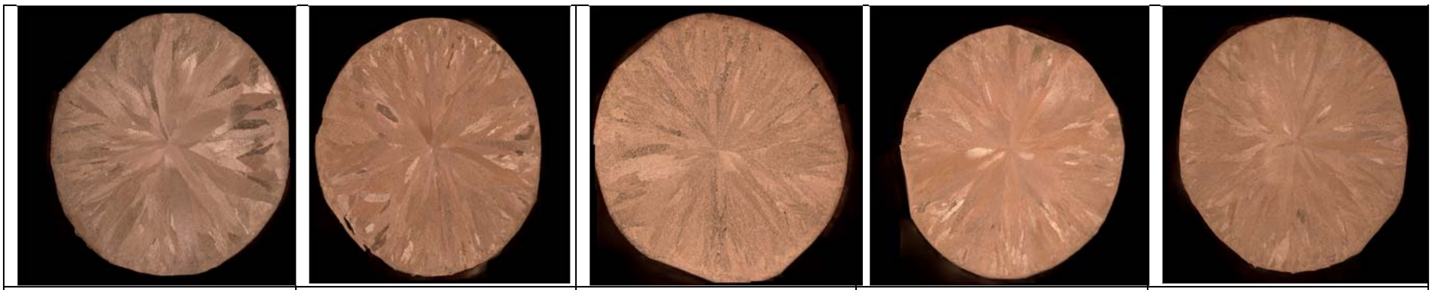
Table 5. Average elongation percentage of CuSnP samples

Sample	Rod dia (mm)	Die	Pull Distance (mm)	Pull Dwell (sec)	Acceleration (sec)	Deceleration (sec)	Casting Speed (mm/min)	Water Flow Rate (ltrs/min)	Tensile Strength (MPa)	Average Elongation Percentage (%)
Cast 1	8	Graphite	10	0	0.02	0.02	3500	15	310	10
Cast 2	8	Graphite	10	0	0.02	0.02	3500	20	301	12
Cast 3	8	Graphite	10	0	0.02	0.02	3500	30	267	15
Cast 4	8	Graphite	10	0	0.02	0.02	3500	40	262	22
Cast 5	8	Graphite	10	0	0.02	0.02	3500	45	248	25



Tensile strength	Elongation percentage

Fig.2 Tensile strength and elongation percentage of CuSnP samples



15 (ltrs/min)	20 (ltrs/min)	30 (ltrs/min)	40 (ltrs/min)	45 (ltrs/min)

Fig.3 Comparison grain structure of CuSnP samples

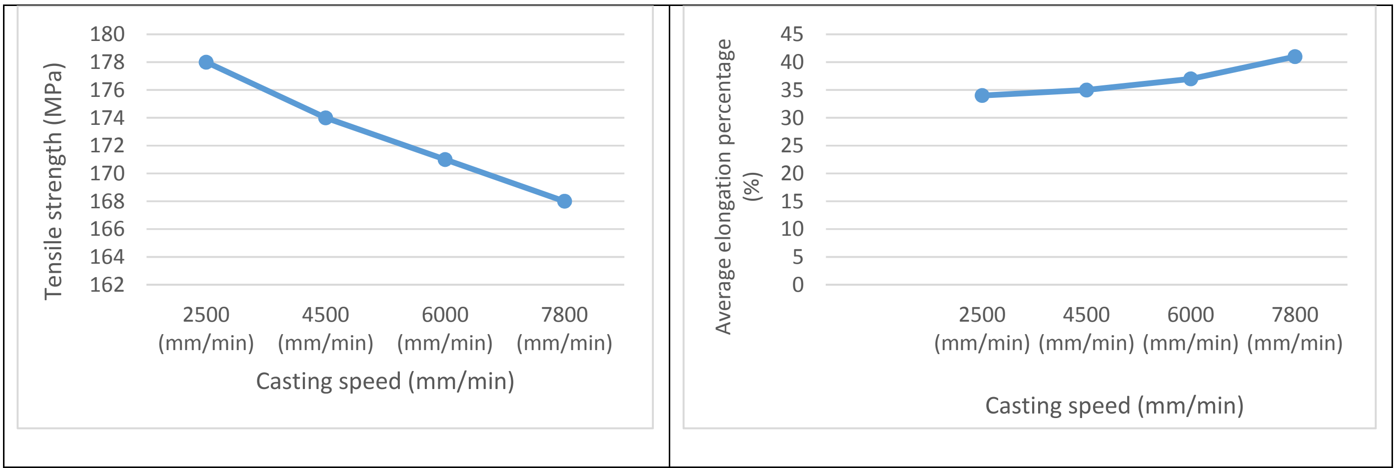
4.2 Casting Speed

In the continuous casting process, casting speed is one of the most important parameters that influence the metallurgical properties of as-cast metals. On the other side, the casting speed, which is directly related to productivity of the machine, is one of the most important parameters for continuous casting. So it is very important to pay attention to a proper determination of the casting speed.
The aim of this section was to investigate the impact of the casting speed on the mechanical properties of continuous cast OFCu copper rod.
Although casting speed can be calculated as a combination of steps i.e pulling time, dwell time, push back and acceleration/deceleration time, this calculation is largely theoretical due to the vagaries of the servo system. For this reason, in this research, the casting speed is calculated by physical measurement of the as-cast rod over a specified time e.g mm/min or m/min.
To study the effect of casting speed in continuous casting of copper alloys, the investigation has been performed with four different casting speeds. Mechanical properties of copper alloy tested, ranging from low up to high casting speeds, were measured, and the results were analysed as shown the following Table and Figures. A strong correlation of the tensile strength and elongation percentage with the casting speed was observed.
For oxygen free copper obtained under industrial conditions, an increase in tensile strength was observed with a decrease of casting speed. For material obtained at a casting speed of 2500 mm/min., the value of tensile strength is equal to approx. 178 MPa. However, for the oxygen free copper sample cast at a higher speed of 7800 mm/min., tensile strength was at a lower level of 168 MPa. This is a significant difference taking into account the change of only casting speed with no difference in the chemical composition of the material or the general method of production. It was found that the casting speed could improve the elongation of samples from 34 % expanding to 41 %.
The reason for this increase in elongation and significant difference in tensile strength is because the casting speed affects the structure formation during solidification. This is the influence of cooling conditions. The other reason for this is that increasing casting speed leads to a change in the heat conduction and solidification conditions, which results in making it possible to obtain a structure with finer grains. This is based on a thermal change as a result of fact that the higher the casting speed gets, the faster the material goes from liquid to solid. The measured average elongation percentage and tensile strength is shown in following table and figures.
Figures 5 and 6 shows cross and longitudinal sections of continuously cast rods after cutting, polishing and etching, solidified at four different pulling speeds. From these, it can be seen that,

in the cross section, the grains are radial from the surface to the centre, and in the longitudinal section, there is a centre line. By comparing the physical and mechanical properties of OFCu copper rods it can be concluded that the mechanical properties have a correlation with grain size, and high mechanical properties are achieved by small grain structure. By observing the cross section of samples, it can be clearly seen that, when casting speed was increased from 2500 mm/min to 7800 mm/min, significant reduction of grain structure were observed. With an increasing of the casting speed, the grain structure tends to become finer in structure.
The longitudinal section shows, at low casting speeds, the columnar grains have a tendency to align along the longitudinal axis of the rod whereas, at higher casting speed, they grow more or less perpendicularly to the rod surface. This observation is because faster cooling is results in increase the amount of grain boundaries. It is known from the above observation on the metallography analysis of grains that the number of columnar grains increases after grain refining by increasing the casting speed. As is well known, smaller grains have greater ratios of surface area to volume, which means a bigger ratio of grain boundaries to dislocations. The more grain boundaries that occur, the higher strength [21,22].

Table 6. Tensile strength and average elongation percentage of OFCu samples

Sample	Rod dia (mm)	Die	Pull Distance (mm)	Pull Dwell (sec)	Acceleration (sec)	Deceleration (sec)	Water Flow Rate (ltrs/min)	Casting Speed (mm/min)	Tensile Strength (MPa)	Average Elongation Percentage (%)
Cast 1	8	Graphite	0.5	0.2	0.005	0.005	45	2500	178	34
Cast 2	8	Graphite	0.5	0.2	0.005	0.005	45	4500	174	35
Cast 3	8	Graphite	0.5	0.2	0.005	0.005	45	6000	171	37
Cast 4	8	Graphite	0.5	0.2	0.005	0.005	45	7800	168	41

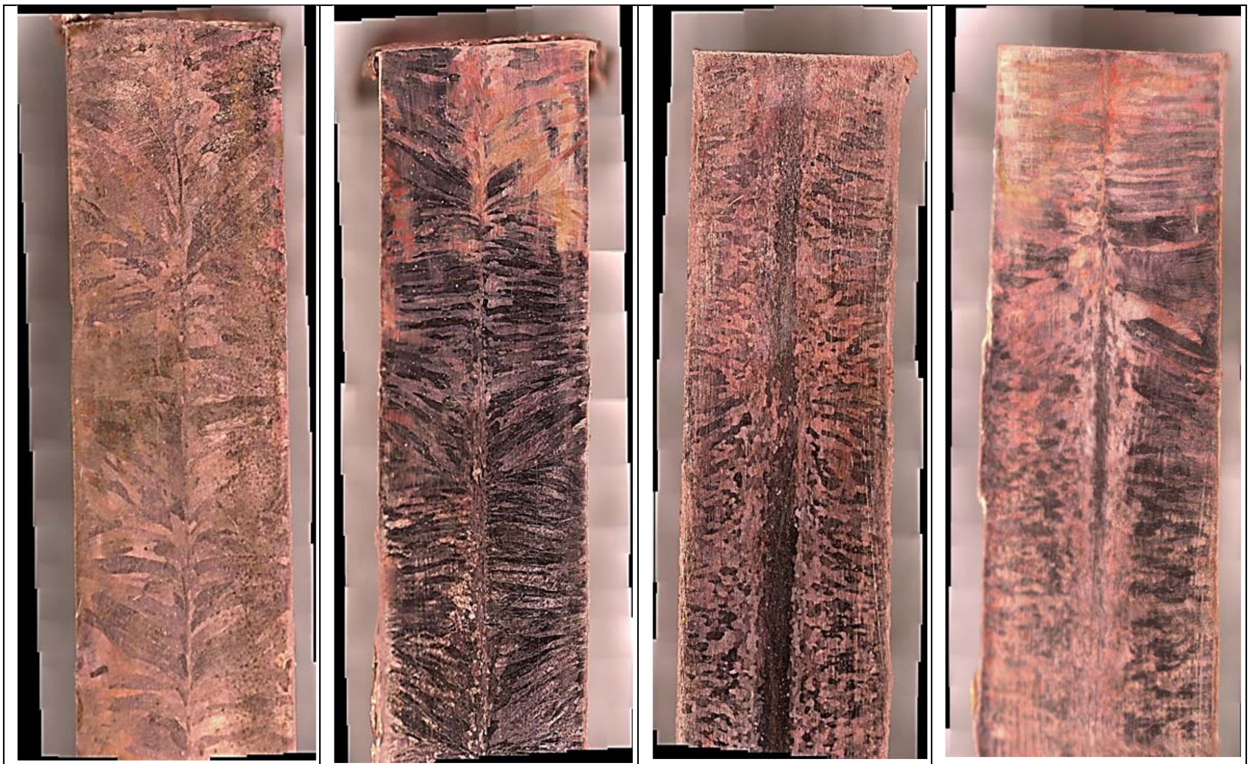


Tensile strength	Elongation percentage

Fig. 4. Tensile strength and elongation percentage of OFCu samples

2500 (mm/min)	4500 (mm/min)	6000 (mm/min)	7800 (mm/min)

Fig.5 Comparison grain structure of OFCu samples (Cross section)



2500 (mm/min)	4500 (mm/min)	6000 (mm/min)	7800 (mm/min)

Fig.6 Comparison grain structure of OFCu samples (Longitudinal section)

4.3 Alloying Elements

The tensile tests were performed on various samples using an Instron machine. Table 7 shows the results obtained from the tensile test carried out on various samples of CuZr alloy, while Figures 7, 8 and 9 depict the relationship of the ultimate tensile strength, percentage elongation and addition of alloying element for the alloys used in this study.

It was considered that the decrease in elongation and increase in strength of continuous cast copper-zirconium alloy is mainly dependent on the solid solubility of the particular element in copper. Additives to pure copper increase its strength and reduce its elongation depending

upon the element and amount in solid solution. Alloying additions can also change the microstructure of the material.
The present results show that this is the most important variable, explaining about 200% of the variance on ultimate tensile strength and elongation percentage. So, the present study shows that the alloying element significantly affects the mechanical properties.
This is because the pure copper is soft and malleable, and small amounts of an alloying element added to molten copper will completely dissolve and form as a homogeneous microstructure. In fact, zirconium can dissolve as individual atoms when added to molten copper and may remain dissolved when the material has solidified and been cooled down to room temperature. However this is depends on the solid solubility of the particular element in copper [23].
The maximum solubility of zirconium metal is about 0.15% by weight and CuZr alloys with zirconium contents varying from 0.01%, or even less, up to 0.15% can be made possessing exceptionally good properties. This solid solubility is at 972 degrees centigrade, which is the assessed temperature of the eutectic reaction of liquid to solid. In the higher zirconium content alloys, some CuZr-rich areas remain at the grain boundaries, providing an objectionable second phase, which may lead to unsoundness in the metal as well as various processing complications and difficulties [24]
The work was continued using a metallography procedure to examine the grain structure of each specimen and the effect of the alloying elements on the size of the secondary dendrite arm spacing (SDAS), which is defined as the distance between the protruding adjacent secondary arms of a dendrite. This was investigated using a “KEYENCE” digital optical microscope.
The result is presented in the following figures and tables. It has been shown that alloying elements have a significant influence on the refinement of the grains. It is clearly shown that the space between dendrite arms decreased by increasing amount of alloying element (zirconium). Higher concentrations of alloying element cause precipitation of finer dendritic grain. Cast samples having a finer microstructure show better tensile strength. This improvement is related to a lower SDAS value.

Table 7. Tensile strength and elongation percentage of CuZr samples

Sample	Rod dia (mm)	Die	Pull Distance (mm)	Pull Dwell (sec)	Acceleration (sec)	Deceleration (sec)	Water Flow Rate (ltrs/min)	Casting Speed (mm/min)	Zirconium percentage (%)	Tensile Strength (MPa)	Average Elongation Percentage (%)
Cast 1	12	Graphite	9	0.5	0.2	0.2	45	1400	2.67	201	6
Cast 2	12	Graphite	9	0.5	0.2	0.2	45	1400	2.80	272	4
Cast 3	12	Graphite	9	0.5	0.2	0.2	45	1400	3.45	484	3
Cast 4	12	Graphite	9	0.5	0.2	0.2	45	1400	6.80	645	2

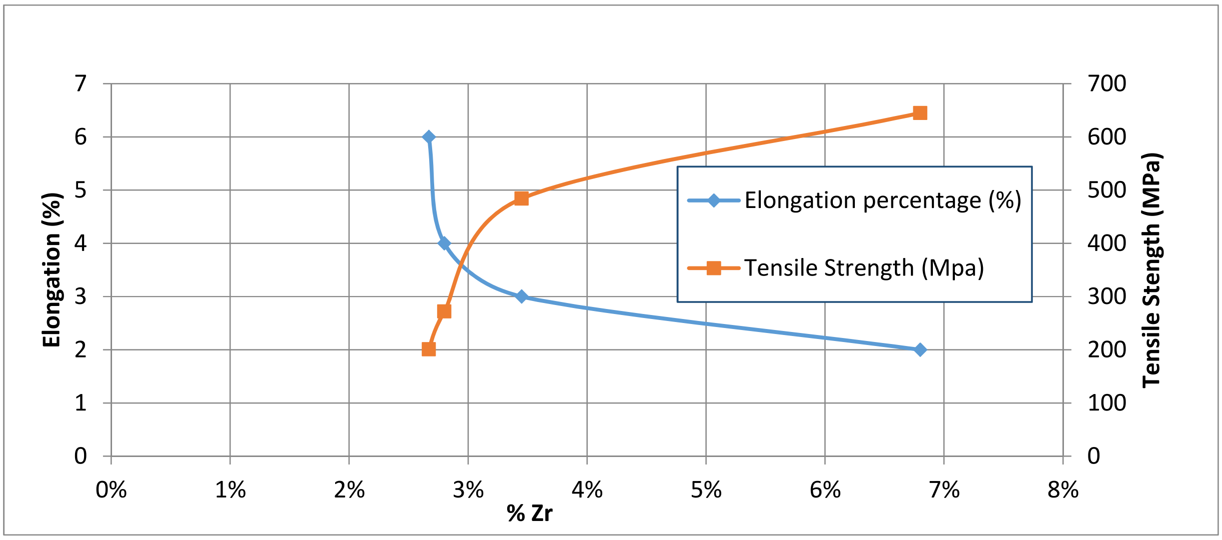
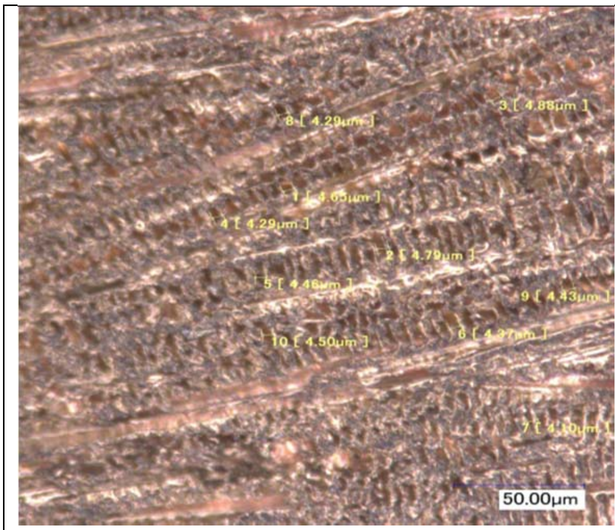
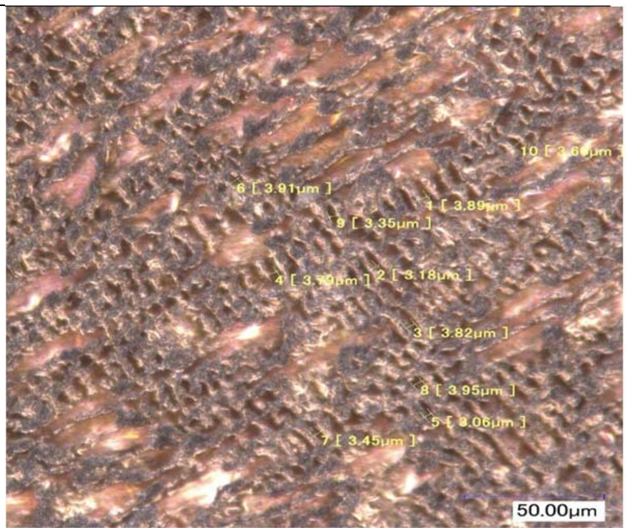
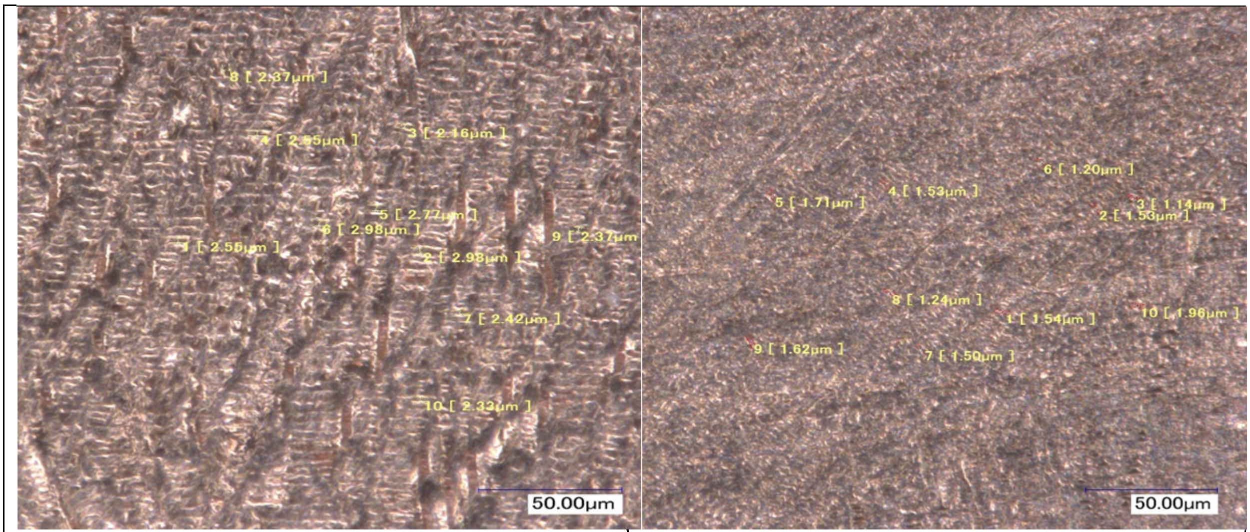


Fig. 7. Tensile strength and elongation percentage of CuZr samples

	
2.6% Zr	2.8% Zr



3.45% Zr	6.8% Zr

Fig.8 Grain structure of CuZr samples

Table 8. Second dendrite arm space of CuZr samples

Zirconium Percentage (%)							
2.6% Zr		2.8% Zr		3.45% Zr		6.8% Zr	
Reading	SDAS (µm)	Reading	SDAS (µm)	Reading	SDAS (µm)	Reading	SDAS (µm)
1	4.65	1	3.89	1	2.55	1	1.54
2	4.79	2	3.18	2	2.98	2	1.53
3	4.88	3	3.82	3	2.16	3	1.14
4	4.65	4	3.79	4	2.55	4	1.53
5	4.46	5	3.06	5	2.77	5	1.71
6	4.37	6	3.91	6	2.98	6	1.2
7	4.1	7	3.45	7	2.42	7	1.5
8	4.29	8	3.98	8	2.37	8	1.24
9	4.43	9	3.35	9	2.37	9	1.62
10	4.5	10	3.61	10	2.33	10	1.96

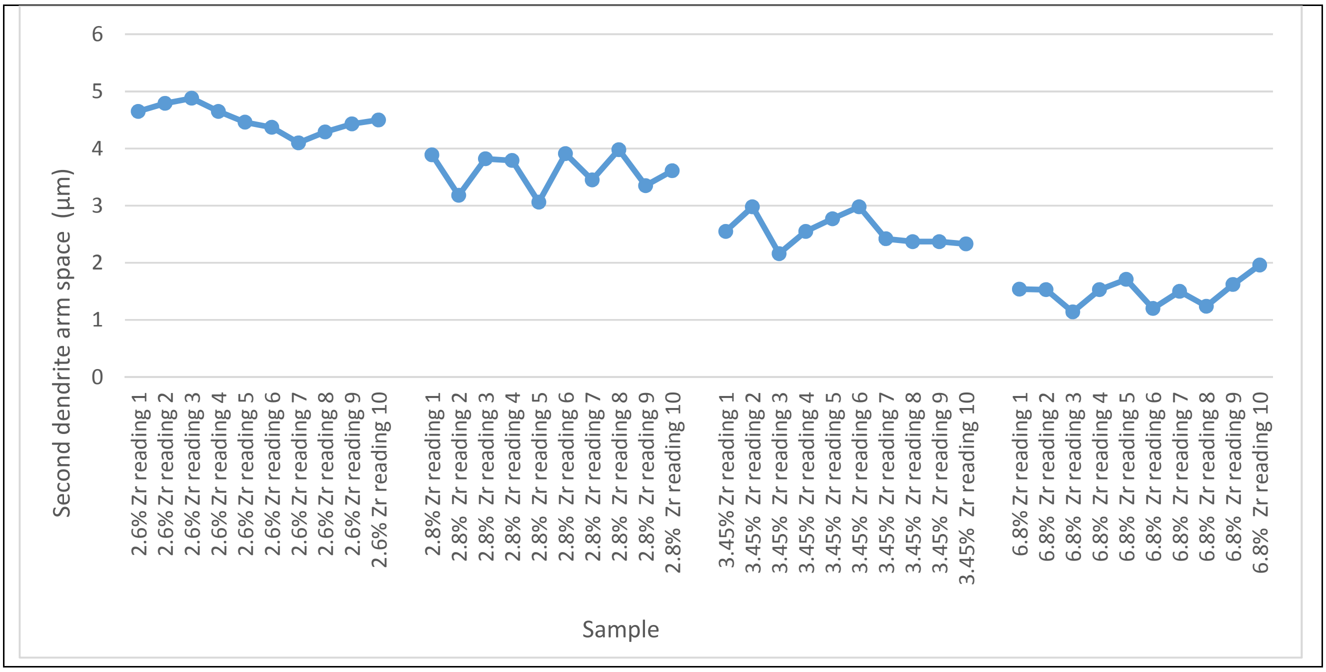


Fig.9 Second dendrite arm space of CuZr samples

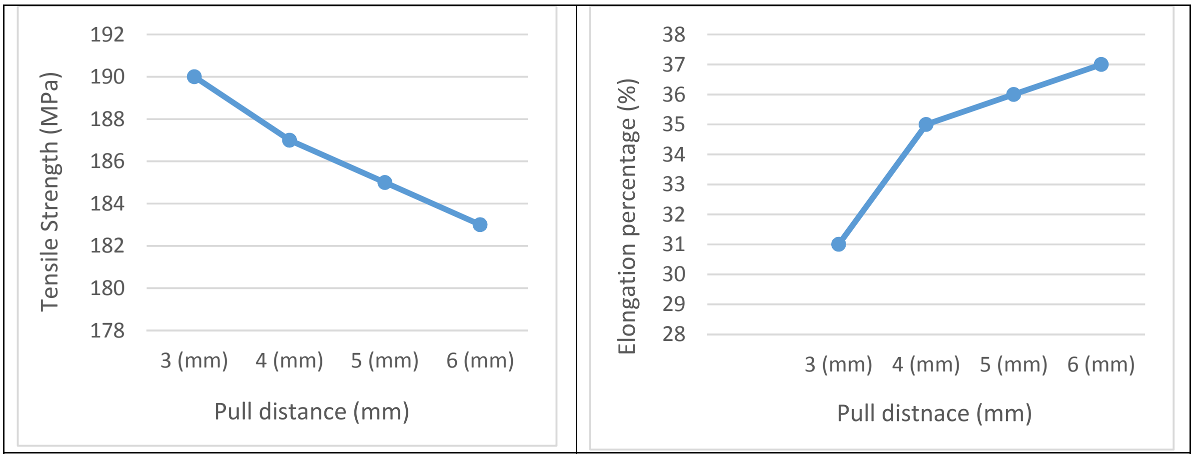
4.4 Pull Distance

In this section, various pull distances (for withdrawing the cast copper in the vertical direction) were tried from the die. Results of the mechanical tests are presented in Table 9 and Figures 10 and 11.The figures shows the effect of pull distance on the elongation percentage of continuous cast CuSn alloys. It can be noticed that the increase of pull distance from 3mm to 6mm gives a slightly increase in the elongation percentage from 31% to 37%.

Increasing pull distance is equal to increasing the casting speed. According to the equation proposed by Kumar, a decrease in the solidification time is equal to increasing the cooling rate. Various researchers mention that the cooling rate is an important processing parameter which affects the mechanical behavior. It has been reported that the solidification time has a significant effect on the ductility of materials [25]. Mei et al previously reported that the faster cooling rate increases the ductility and elongation to failure when the microstructure becomes more refined, while faster cooling rate during solidification and a fine microstructure provides a better set of mechanical properties than a coarse microstructure. Hence, larger pull distance will improve the ductility of continuous cast copper alloy [26, 27].

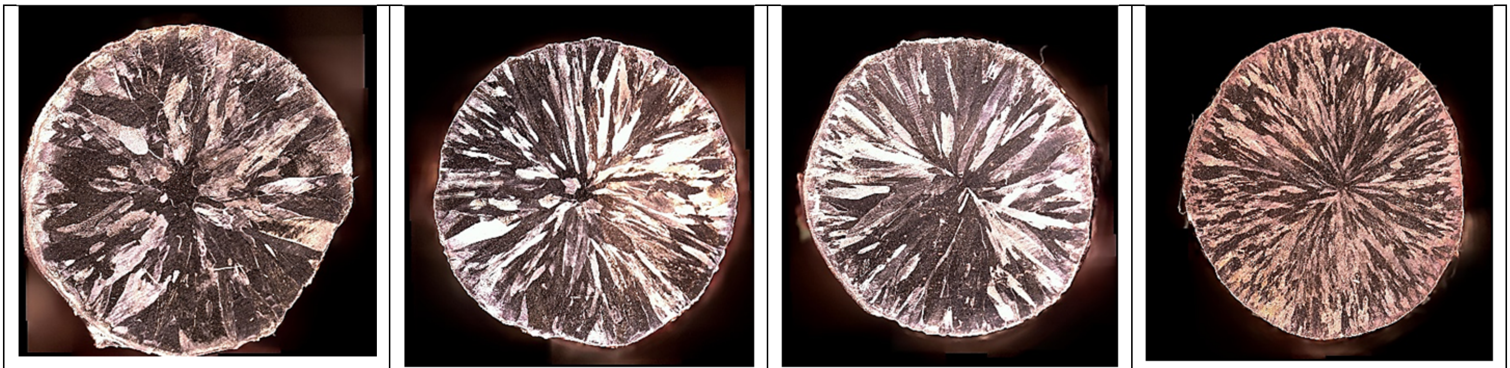
Table 9. Average elongation percentage of CuSn samples

Sample	Rod dia (mm)	Die	Pull Dwell (sec)	Acceleration (sec)	Deceleration (sec)	Water Flow Rate (ltrs/min)	Casting Speed (mm/min)	Pull Distance (mm)	Tensile Strength (MPa)	Average Elongation Percentage (%)
Cast 1	12	Graphite	0.015	0.010	0.010	55	970	3	190	31
Cast 2	12	Graphite	0.015	0.010	0.010	55	1700	4	187	35
Cast 3	12	Graphite	0.015	0.010	0.010	55	2100	5	185	36
Cast 4	12	Graphite	0.015	0.010	0.010	55	2700	6	183	37



Tensile strength	Elongation percentage

Fig. 10. Tensile strength and average elongation percentage of CuSn samples



3mm pull distance	4mm pull distance	5mm pull distance	6mm pull distance

Fig.11 Grain structure of CuSn samples

4. Conclusions and Future Work

The effects of water flow rate, casting speed, addition of alloying elements and pull distance on the mechanical properties of continuous cast copper alloys were investigated using tensile machine. From the above experimental results, some important conclusions can be drawn:

1. Results showed that when cooling water flow rate was increased, an improvement of elongation percentage was observed.
2. When casting speed increased, a significant improvement of physical and mechanical properties of copper alloys were observed.
3. The addition of some alloying elements, notably Zr, improved the tensile strength of continuous cast copper alloy. However, the elongation percentage of this alloy decreased with an increase in the amount of alloying element.
4. The addition of zirconium reduces slightly the size of SDAS of continuously cast copper rod.

5. Pull distance strongly affect the physical and mechanical properties of continuous cast copper.
6. With the increasing of the casting speed, water flow rate and pulling distance, the grain structure tends to become finer in continuous cast copper alloy.
7. A limitation observed in this study is that, once the casting speed, water flow rate and pull distance are increased, it can result in lower casting quality, up to fracture. At high casting speed, low pull distance and low water flow rate parameters should be avoided.
8. As for future work, this research can be extended by comparing the influence of other thermal factors on the structure and mechanical properties of continuous cast copper alloy such as; melt temperature, cleanout cycle, continuous casting direction (horizontal /vertical) and super-cooler size.

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